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Short report

Reliability of the lateral angle of the internal auditory canal for sex determination of subadult skeletal remains

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ABSTRACT

When creating a basic biological profile, determining the sex of subadult skeletal remains is always problematic and several methods for sex determination have been proposed over time. The lateral angle of the internal auditory canal has been described as a good sex predictor in adults, and here we test its reliability for sex determination of subadults. The reliability of this method was assessed on a sample of 47 Portuguese known sex and age skeletons representing individuals from birth to 15 years of age. The lateral angle was measured on-screen using the Adobe Photoshop CS2® software, from photographs of bissected lateral angle casts. The measurements were performed by three different researchers in order to evaluate intra- and inter-observer variation. Our results demonstrate reasonable repeatability and replicability of the on-screen measurements. We used a 45° sectioning point to allocate individuals in the sample according to sex and attained 62.9% accuracy in sex determination using the lateral angle. When broken down by age, the least accuracy was observed for the 6–15 years-old group (54.5%) and the greatest accuracy was achieved for the 2–5 years-old (75.0%), but still low overall. The use of a sample-specific sectioning point did not improve the results. Although sexual dimorphism is statistically significant between female and male subadults, the lateral angle failed to consistently discriminate individuals according to sex.

1. Introduction

Sex determination of subadult skeletal remains using osteological indicators has not been as successful as that of adults. This results from the low sexual dimorphism in most anatomical regions prior to puberty and incomplete sexual expression before adulthood is reached. Nonetheless, a number of sex determination methodologies with various successful rates have been specifically developed for subadult skeletons.[1,2,3,4,5,6] Regrettably, most methods do not provide reliable results and seem to have population and age-specific limitations.

Norén et al.[7] have recently used the lateral angle of the internal auditory canal (IAC) for successful sex determination of adults (83.0%). However, using the same method, Graw et al.[8] only correctly classified 66.3% of their sample according to sex. The lateral angle is formed by the IAC and the external surface of the petrous portion measured on a cast. According to Norén et al.,[7] sexual dimorphism in the lateral angle of the IAC results from the male cranial base being broader which, supposedly, influences the angle between the brain stem and the auditory canal during growth of the cranium. Considering that the cranium is the earliest structure in the skeleton to reach adult size,[9] adult sex differences in the lateral angle may already be discernible in subadult remains. The petrous bone reaches 46% of its adult size during the first 2 years of life, slowing its growth noticeably afterwards until finally stopping at 20 years of age.[7] Although Norén et al.[7] attempted to sex 4 subadults from the lateral angle and achieved a correct sex allocation accuracy of 75%, their test is insufficient to claim successful subadult sex determinations. The purpose of this article is two-fold. First, we wish to test the repeatability and replicability in measuring the lateral angle. Secondly, we wish to assess the accuracy of the lateral angle method in determining the sex of subadult skeletal remains.

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Table 1
Composition of the sample by sex and age.

Age	Male	Female	Total
0	1	1	2
1	9	4	13
2	3	1	4
3	2	1	3
4	2	5	7
5	2	0	2
6	0	1	1
7	3	0	3
8	2	0	2
9	2	0	2
10	0	2	2
11	2	0	2
14	1	0	1
15	2	1	3

2. Methods

The research was completed using a sample composed of 47 subadult skeletons of know sex and age from the identified skeletal collection curated at the National Museum of Natural History in Lisbon, Portugal. The sample includes 16 females and 31 males, with ages ranging from birth to 15 years-old (Table 1). The sample only included fragmentary, autopsied or otherwise unfused skulls, of individuals under 20 years of age, which allowed direct access to the internal cranial cavity and to the IAC.

Since the IAC cannot be accessed directly, a cast was obtained by using a light bodied dental casting material. Coltène President® was selected for the procedure according to the experimentation completed by Norén et al..[7] This silicone-based material was introduced in the IAC after cleaning and coating of the bone surface with vaseline. This was done to facilitate removal of the cast after setting.[7] Once removed, the cast was bisected with a scalpel following the major axis of the IAC. The lateral angle[7] is measured on the intersection of the posterior external surface of the petrous portion and the adjacent edge of the IAC (Fig. 1). An orthogonal picture of the bisected face of the cast was taken and then used to assess the angle with Adobe Photoshop CS2® measuring tools. Two lines were drawn parallel and overlaying the two axes which comprise the lateral angle to better guide the measurements. In some cases, the lateral angle was not measured because the unevenness of the bone surface did not permit the reliable drawing of these lines.

A total of 75 internal auditory canals were casted, of which 36 are from the left temporal bone and 39 are from the right side. Those incompletely casted were removed from the selected sample.

Table 2
Technical error of measurement (TEM) and coefficient of reliability (R) for the intra- and inter-observations.

	Observer 1	Obs 1 vs Obs 2	Obs 1 vs Obs 3	Obs 2 vs Obs 3
TEM	3.013	5.728	5.043	5.504
R	0.944	0.819	0.805	0.804

Each individual measurement was repeated three times and the median value was recorded. Repeatability (intra-observer variation) and replicability (inter-observer variation) were assessed by repeating the whole procedure on 18 petrous bones of both sides and calculating the technical error of measurement and the coefficient of reliability.[10]

The measurements of the right side were compared with those from the left on 24 individuals with bilateral measurements. The Wilcoxon signed-rank test revealed statistically non-significant side differences ($p = 0.283$) between the left measurements (mean = 44.2°) and the right measurements (mean = 46.0°). Consequently, only the left casts were used for sex determination, being the right casts used whenever the left ones were unavailable.

Each individual was allocated as to sex according to the 45° sectioning point recommended by Norén et al..[7] Measurements greater than 45° were assigned to females and those lower than 45° were attributed to males. The results were broken down by age cohorts in order to assess age-specific differences in sex determination success. We considered three age groups according to mean ages of attainment of adult cranial size as described by Norén et al.[7] and Humphrey.[9] The sample was separated at 2 and 6 years of age. The age of 2 represents the age at which approximately 50% of adult cranial size is reached and the age of 6 represents the age at which 90% of adult cranial size is attained.

In addition to classifying sex according to Norén et al.,[7] an attempt to improve sex determination with this method was carried out by finding a specific sectioning point for our sample. This was done by calculating the sex-pooled weighted arithmetic mean value for the lateral angle and subsequently using it to reclassify all individuals as of sex as described by Albanese et al..[11]

3. Results

The technical error of measurement of the lateral angle measurements for the intra-observations was of 3.013° with a coefficient of reliability of 0.944 while the inter-observer variation ranged between 5.043° and 5.728° degrees with the coefficient of reliability presenting results slightly higher than 0.800 (Table 2).

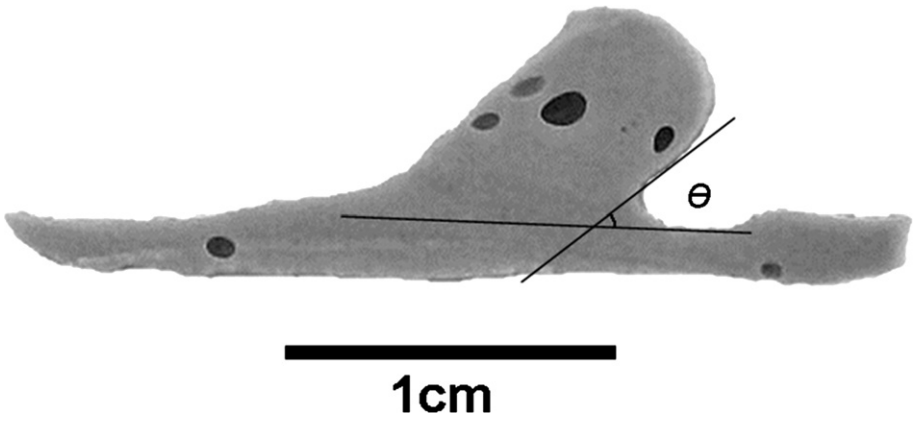

Fig. 1. Illustration of the Lateral Angle (Θ) of the internal auditory canal.

Table 3
Sex determination accuracy broken down by sex and age group.

Age groups (years)	Females	Males	Total
0 to 1	80.0% ($n = 5$)	42.9% ($n = 7$)	58.3% ($n = 12$)
2 to 5	83.3% ($n = 6$)	66.7% ($n = 6$)	75.0% ($n = 12$)
6–15	50.0% ($n = 2$)	55.6% ($n = 9$)	54.5% ($n = 11$)
Total	76.9% ($n = 13$)	54.5% ($n = 22$)	62.9% ($n = 35$)

The female angle mean is 49.7° ($n = 13$, s.d. = 7.846) and the male angle mean is 41.1° ($n = 22$, s.d. = 11.769). A statistically significant difference was found between the two means (t-test = 2.326; df = 33; $p = 0.026$). The correct sex classification results using the 45° sectioning point, in the total sample and when it is broken down by age group, is given in Table 3. The percentages of correct sex allocation are generally low with females showing better results than males. Greater accuracy was found for the 2–5 years-old age group, and lesser accuracy for the 0–1 years-old and the 6–15 years-old age groups. The sample-specific sectioning point obtained was 44°, which produced similar results to that of the 45° sectioning point. When using the new sectioning point, the total correct sex classification was of 62.9% (females = 77.0%, males = 54.5%). When the measurements are analysed in greater detail, no lateral angles smaller than 30° were recorded for females while no lateral angles larger than 60° were recorded for males (Table 4).

4. Discussion

Our results demonstrate that the lateral angle technique is repeatable with a good degree of reliability. However, the replicability was not as satisfactory and the coefficient of reliability for the inter-observer TEM demonstrates that a considerable portion of the measurement variance present in the sample was the result of measurement error.

We did not find statistically significant lateral differences in angles, but the difference between the female and the male angle means is statistically significant. However, our results demonstrate that the internal auditory canal cannot be reliably used to correctly allocate subadult skeletal remains to either sex. The sex allocation was slightly better for the female group than for the male group. Apparently, this is the result of a broader distribution of male lateral angles (min. 18°; max. 59°) in contrast to females (min. 39°; max. 69°). This explains the better results for sex allocation obtained for the 2 to 5 years-old group in comparison to the other two age groups. Contrary to the former, these are composed mainly of males and this caused lower accuracies regarding sex allocation. In addition, conclusions drawn from differences in accuracy between age cohorts must be addressed with caution due to the small sample size of each age group. This is especially true for the 6 to 15 years-old age group which is composed by the smallest and most uneven sample according to sex.

Table 4
number of females and males in function of lateral angle intervals.

Angle intervals	Females	Males
>60°	2	0
50 to 59.9°	4	5
40 to 49.9°	6	10
30 to 39.9°	1	3
<30°	0	4

An increasing sexual dimorphism expression of the lateral angle with age is not detectable by looking at the results. However, the mean lateral angle seems to increase for females after 1 year-old and decrease for males after the first year of age. In the 0 to 1 year-old group, we obtained a 48° mean angle for both females and males. In the 2 to 5 years-old group, we recorded 49° for female mean angle and 36° for male mean angle. Finally, we obtained 56° for the female mean angle and 39° for the male mean angle in the 6 to 15 years-old age group. This is an interesting outcome that deserves further consideration on a larger sample more evenly composed of both sexes. The calculation of the sample-specific sectioning point did not improve correct sex allocation.

Our inability to discriminate sex on the subadult sample mirror to some degree the results obtained by Graw et al[8] on an adult sample, who, despite finding significant differences between female and male lateral angles' means, were not able to correctly classify more than 66% of their sample using discriminant function analysis. Likewise, despite our study revealing significant sexual dimorphism of the lateral angle we failed to use it to correctly sex allocate the most part of our sample. At best, results demonstrate that large lateral angles tend to be from females and small ones tend to be from males.

Some methodological-related problems leading the casts to not fully reproduce the internal auditory canal may have contributed for the poor results obtained. For instance, the vaseline applied before the casting may have caused pseudo-reliefs affecting the measurement of the lateral angle, although this was not discernible at a gross level of observation. In addition, complete orthogonality of photos may not have been achieved for the on-screen technique, introducing slight variations in the plan of the bisected face. Therefore, the method may have some replicability problems. Nevertheless, the on-screen technique revealed low intra- and inter-observer error and therefore presents consistent results.

This study confirms the low reliability of techniques which have relied on the identification of adult sex-related features for the sex determination of subadult skeletons, such as those proposed for the illium,[1,2,3] [12] and cranium.[4] Possibly, the only exceptions are the studies carried out by Cardoso[5] and Rogers .[13] The latter achieved an accuracy of 81% on a combined sample of adolescent skeletons, between the ages of 11 and 20 years, when testing the method of morphological sex determination using the distal humerus described for adult individuals.[14] Cardoso[5] shows that the crown dimensions of the permanent canine are reliable for sex determination of subadult individuals of about 6 years of age and older. Regrettably, our results demonstrate that the lateral angle method cannot join this reduced set of methodologies regarding the sex determination of subadult skeletal remains.

5. Conclusion

The results here obtained are in contrast with those obtained by Norén et al.[7] who were able to correctly determine the sex of more than 80% of their adult sample and mirror those from Graw et al.[8] who were only able to correctly discriminate two thirds of their sample composed of adult individuals. Given this two different outcomes, it is unclear if the failure of the lateral angle method on a subadult sample is due to a lack of considerable sexual dimorphism on subadults or if this is absent in adults as well. More research on adult samples must be carried out to help clarify this issue.

Conflict of interest

The authors declare that they have no conflict of interest.

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